$\bar{p}p \to \chi_{c12} \to J/\psi\gamma \to \ell^+\ell^-\gamma$
$\bar{p}p \to X(3872) \to J/\psi\pi\pi \to \ell^+\ell^-\pi\pi$

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INFN Ferrara

PANDA Collaboration Meeting - GSI
10th - 13th June 2014

Outline

- $\bar{p}p \rightarrow \chi_{c12} \rightarrow J/\psi\gamma \rightarrow \ell^+\ell^-\gamma$
- $\bar{p}p \rightarrow X(3872) \rightarrow J/\psi\pi^+\pi^- \rightarrow \ell^+\ell^-\pi^+\pi^-$
- $\bar{p}p \rightarrow X(3872) \rightarrow J/\psi\pi^0\pi^0 \rightarrow \ell^+\ell^- 4\gamma$

For each process the time needed to achive 5σ significance has been calculated for:

  - $\mathcal{L}$=10^{32} $\text{cm}^{-2}\text{s}^{-1}$
  - $\mathcal{L}$=10^{31} $\text{cm}^{-2}\text{s}^{-1}$
  - $\mathcal{L}$=10^{30} $\text{cm}^{-2}\text{s}^{-1}$
  - Different detector scenario

$\overline{p}p \rightarrow \chi_{c12} \rightarrow J/\psi\gamma \rightarrow \ell^+\ell^-\gamma$

$$\overline{p}p \rightarrow \chi_{c12} \rightarrow J/\psi\gamma \rightarrow \ell^+\ell^-\gamma$$

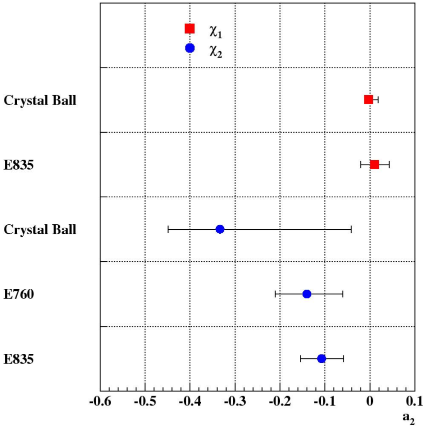
Radiative transitions of the χ_{cJ} charmonium states

The measurement of the angular distributions in the radiative decays of the χ_c states provides the multipole structure of the radiative decay and the properties of the $\overline{c}c$ bound state.
The angular distributions of the χ_{c1} and χ_{c2} are described by 4 indipendent parameters:

$$a_2(\chi_{c1}), a_2(\chi_{c2}), B_0^2(\chi_{c2}), a_3(\chi_{c2})$$

where a_2 and a_3 are the decay amplitudes, B_0^2 is the production amplitude.

χ_{c1} and χ_{c2} angular distributions: Previous results



$$\left(\frac{a_2(\chi_{c1})}{a_2(\chi_{c2})}\right)_{Th} = \frac{\sqrt{5}}{3}\frac{E_\gamma(\chi_{c1}\to J/\psi\gamma)}{E_\gamma(\chi_{c2}\to J/\psi\gamma)} = 0.676$$

McClary and Byers (1983) predict that ratio is indipendent of c-quark mass and anomalouse magnetic moment

E835 have been measured for the first time this ratio:

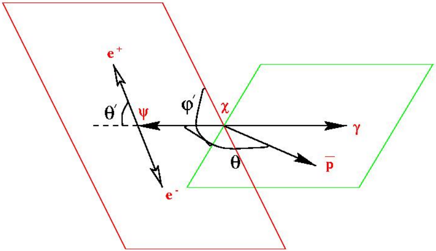
$$\left(\frac{a_2(\chi_{c1})}{a_2(\chi_{c2})}\right)_{E835} = -0.02 \pm 0.34$$

Experimental result is $\sim 2\sigma$ away from prediction.

High statistics measurements of these angular distributions are needed to solve this question

E835 Reference "Ambrogiani et al. Physical Review D, Vol. 65, 05002"

χ_{c1} and χ_{c2} angular distributions



- θ is the polar angle of the J/ψ with respect to the antiproton in the $\bar{p}p$ center of mass system
- θ' is the polar angle of the positron in the J/ψ rest frame with respect to the J/ψ direction in the χ rest of mass system
- ϕ' is the azimuthal angle between the J/ψ decay plane and the χ_c plane

$\bar{p}p \rightarrow \chi_{c1} \rightarrow J/\psi\gamma$

- Production amplitudes: $B_0 = 0$
- Decay Amplitudes: a_2
  $a_2 = 0.002 \pm 0.032 \pm 0.004$

$\bar{p}p \rightarrow \chi_{c2} \rightarrow J/\psi\gamma$

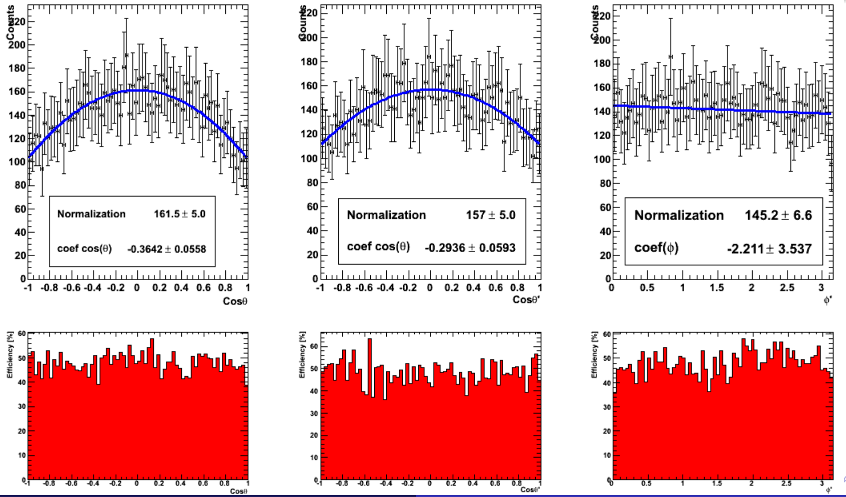
- Production amplitudes: B_0^2
  $B_0^2 = 0.16^{+0.09}_{-0.10} \pm 0.01$
- Decay Amplitudes: a_2, a_3
  $a_2 = -0.076^{+0.054}_{-0.050} \pm 0.009$
  $a_3 = 0.020^{+0.055}_{-0.044} \pm 0.009$

* E835 Collaboration, Nucl. Phys. B 717, 34 (2005)

Angular distributions for $\bar{p}p \rightarrow \chi_{c1} \rightarrow J/\psi\gamma$

The angles distributions corrected with the efficiency, which is presented in the lower part. The angular distributions for the three angles can be approximately written as:

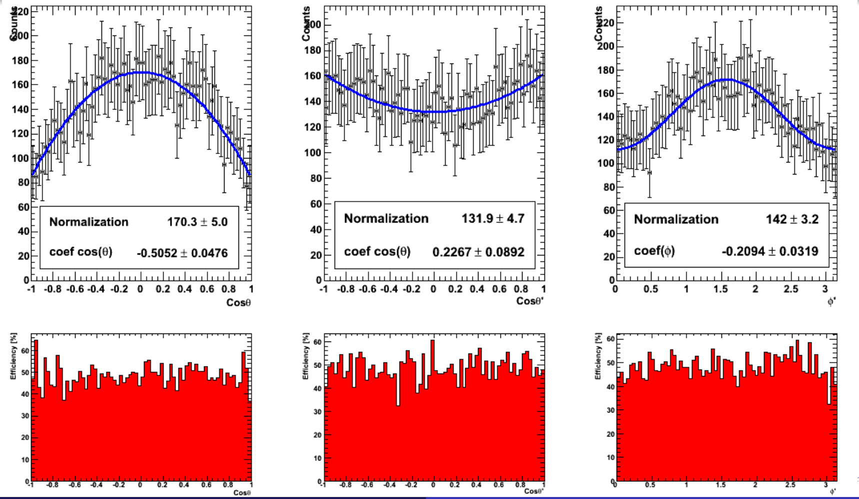
$$W(cos\theta) = 1 - \frac{1}{3}cos^2\theta; \quad W(cos\theta') = 1 - \frac{1}{3}cos^2\theta'; \quad W(\phi) = \text{flat}$$



Angular distributions for $\bar{p}p \rightarrow \chi_{c2} \rightarrow J/\psi\gamma$

The angles distributions corrected with the efficiency, which is presented in the lower part. The angular distributions for the three angles can be approximately written as:

$$W(cos\theta) = 1 - \frac{1}{3}cos^2\theta; \quad W(cos\theta') = 1 - \frac{1}{3}cos^2\theta'; \quad W(\phi') = 1 - \frac{8}{71}cos(2\phi')$$



$\bar{p}p \to \chi_{c1,2} \to J/\psi\gamma \to \ell^+\ell^-\gamma$

Cross sections

Signal

$\sigma(\chi_{c1} \to J/\psi\gamma) \sim 1.7$ nbarn
$\sigma(\chi_{c2} \to J/\psi\gamma) \sim 2$ nbarn
E835 Collaboration, Nucl.Phys.B 717,34 (2005)

Background

Background: $\bar{p}p \to \pi^+\pi^-\pi^0$:
$\sigma(\chi_{c2})$=0.12 mb
CERN-HERA 70-03 (1970)

- Fast Simulation
- $J/\psi \to e^+e^-$; $J/\psi \to \mu^+\mu^-$
- PID for Electrons: 1 Electron Loose; 1 Electron Tight (as in the Physics Book)
- PID for Muons: 1 Muon Loose; 1 Muon Tight (as in the Physics Book)
- PID for Photons: Neutral
- Bremsstrahlung effect for the electrons
- MC Truth Match
- 10.000 events generated
- Decay model: $\chi_{c12} \to J/\psi\gamma$: Chic1toJpsiGam (Chic2toJpsiGam)
- Decay model: $J/\psi \to \ell^+\ell^-$: VLL

4C fit is performed and best χ_{c12} candidate in each event is selected by minimal χ^2

Significance

$$Significance(t) = \sqrt{\mathcal{L}t} \times \frac{\sigma_s \epsilon_s f_{BR}}{\sqrt{\sigma_s \epsilon_s f_{BR} + \sigma_b \epsilon_b}}$$

σ_s=2 nb [Nucl.Phys.B 717,34(2005)]
ϵ_s: known from simulation
σ_b=0.12 mb [CERN-HERA 70-03 (1970)]
ϵ_b=known from simulation

$$f_{BR}=\begin{cases} \mathrm{BR}(\chi_{c1} \to J/\psi\gamma) \times BR(J/\psi \to \ell^+\ell^-) = 0.020 \\ \mathrm{BR}(\chi_{c2} \to J/\psi\gamma) \times BR(J/\psi \to \ell^+\ell^-) = 0.011 \end{cases}$$

$BR(\chi_{c1} \to J/\psi\gamma) = 0.34$ [PDG]
$BR(\chi_{c2} \to J/\psi\gamma) = 0.19$ [PDG]

$$BR(J/\psi \to \ell^+\ell^-)=\begin{cases} \mathrm{BR}(J/\psi \to e^+e^-) = 0.0594 \text{ [PDG]} \\ \mathrm{BR}(J/\psi \to \mu^+\mu^-) = 0.0593 \text{ [PDG]} \end{cases}$$

Time needed to achive 5σ significance?

$\bar{p}p \rightarrow \chi_{c1} \rightarrow J/\psi\gamma \rightarrow \ell^+\ell^-\gamma$

$J/\psi \rightarrow e^+e^-$

Detector Setup	ϵ_s (%)	ϵ_b	t ($\mathcal{L} = 10^{32}$)	t ($\mathcal{L} = 10^{31}$)	t ($\mathcal{L} = 10^{30}$)
Full	48.10	1.3×10^{-6}	1.3 days	13.4 days	4.5 months
w/o EmcBarrel	14.15	2.5×10^{-5}	8.8 months	7.4 years	74 years
w/o FwdSpec	40.07	1.2×10^{-6}	1.9 days	19 days	6.3 months
w/o DiscDirc	47.82	1.3×10^{-6}	1.4 days	13.6 days	4.5 months
w/o MvdGem	34.64	1.1×10^{-5}	20.4 days	6.8 months	5.7 years

$J/\psi \rightarrow \mu^+\mu^-$

Detector Setup	ϵ_s (%)	ϵ_b	t ($\mathcal{L} = 10^{32}$)	t ($\mathcal{L} = 10^{31}$)	t ($\mathcal{L} = 10^{30}$)
Full	63.50	1.2×10^{-5}	6.5 days	2.2 months	1.8 years
w/o EmcBarrel	17.88	8.4×10^{-6}	1.9 months	1.6 years	16 years
w/o FwdSpec	54.02	7.8×10^{-6}	5.8 days	1.9 months	1.6 years
w/o DiscDirc	61.02	1.2×10^{-5}	7.0 days	2.3 months	1.9 years
w/o MvdGem	35.67	1.4×10^{-5}	23.7 days	7.9 months	6.6 years

$\bar{p}p \rightarrow \chi_{c2} \rightarrow J/\psi\gamma \rightarrow \ell^+\ell^-\gamma$

$J/\psi \rightarrow e^+e^-$

Detector Setup	ϵ_s (%)	ϵ_b	t ($\mathcal{L} = 10^{32}$)	t ($\mathcal{L} = 10^{31}$)	t ($\mathcal{L} = 10^{30}$)
Full	48.60	1.2×10^{-6}	3.5 days	1.2 months	11.8 months
w/o EmcBarrel	13.90	3.1×10^{-5}	2.9 years	29 years	288 years
w/o FwdSpec	40.80	1.1×10^{-6}	4.7 days	1.6 months	1.3 years
w/o DiscDirc	48.20	1.2×10^{-6}	3.6 days	1.2 months	12.0 months
w/o MvdGem	35.70	3.2×10^{-6}	16.6 days	5.5 months	4.6 years

$J/\psi \rightarrow \mu^+\mu^-$

Detector Setup	ϵ_s (%)	ϵ_b	t ($\mathcal{L} = 10^{32}$)	t ($\mathcal{L} = 10^{31}$)	t ($\mathcal{L} = 10^{30}$)
Full	63.70	1.9×10^{-5}	1.0 months	10.0 months	8.5 years
w/o EmcBarrel	18.60	7.1×10^{-6}	4.4 months	3.7 years	37 years
w/o FwdSpec	56.40	1.5×10^{-5}	1.0 months	10.2 months	8.5 years
w/o DiscDirc	62.90	1.9×10^{-5}	1.0 months	10.5 months	8.7 years
w/o MvdGem	36.15	2.0×10^{-5}	3.3 months	2.7 years	27.4 years

$\bar{p}p \rightarrow X(3872) \rightarrow J/\psi\pi^+\pi^+ \rightarrow \ell^+\ell^-\pi^+\pi^-$

$$\bar{p}p \rightarrow X(3872) \rightarrow J/\psi\pi^+\pi^- \rightarrow \ell^+\ell^-\pi^+\pi^-$$

$\bar{p}p \rightarrow X(3872) \rightarrow J/\psi\pi^+\pi^- \rightarrow \ell^+\ell^-\pi^+\pi^-$

Cross sections

Signal

$\sigma(\bar{p}p \rightarrow X(3872) \rightarrow J/\psi\pi^+\pi^-) \sim 50$ nbarn

Martin J.Galuska, Master Thesis

Background

Background: $\bar{p}p \rightarrow \pi^+\pi^-\pi^+\pi^-$:
σ(3.860 GeV)=0.054 mb

CERN-HERA 70-03 (1970)

- Fast Simulation
- $J/\psi \rightarrow e^+e^-$; $J/\psi \rightarrow \mu^+\mu^-$
- PID for Electrons: 1 Electron Loose; 1 Electron Tight (as in the Physics Book)
- PID for Muons: 1 Muon Loose; 1 Muon Tight (as in the Physics Book)
- Bremsstrahlung effect for the electrons
- MC Truth Match
- 10.000 events generated
- Decay model: $X(3872) \rightarrow J/\psi\pi^+\pi^-$: PHSP
- Decay model: $J/\psi \rightarrow \ell^+\ell^-$: VLL

4C fit is performed and best $X(3872)$ candidate in each event is selected by minimal χ^2

Significance

$$Significance(t) = \sqrt{\mathcal{L}t} \times \frac{\sigma_s \epsilon_s f_{BR}}{\sqrt{\sigma_s \epsilon_s f_{BR} + \sigma_b \epsilon_b}}$$

σ_s=50 nb [Martin J.Galuska, Master Thesis]
ϵ_s: known from simulation
σ_b=0.054 mb [CERN-HERA 70-03 (1970)]
ϵ_b=known from simulation
$f_{BR} = BR(X(3872) \to J/\psi\pi^+\pi^-) \times BR(J/\psi \to \ell^+\ell^-) = 2.97 \times 10^{-3}$
$BR(X(3872) \to J/\psi\pi^+\pi^-) = 0.05$ [Martin J.Galuska, Master Thesis]

$$BR(J/\psi \to e^+e^-) = \begin{cases} \mathrm{BR}(J/\psi \to e^+e^-) = 0.0594 \text{ [PDG]} \\ \mathrm{BR}(J/\psi \to \mu^+\mu^-) = 0.0593 \text{ [PDG]} \end{cases}$$

Time needed to achive 5σ significance?

$\bar{p}p \to X(3872) \to J/\psi\pi^+\pi^- \to \ell^+\ell^-\pi^+\pi^-$

$J/\psi \to e^+e^-$

Detector Setup	ϵ_s (%)	ϵ_b	t ($\mathcal{L} = 10^{32}$)	t ($\mathcal{L} = 10^{31}$)	t ($\mathcal{L} = 10^{30}$)
Full	29.09	1.6×10^{-5}	1.4 days	14.0 days	4.7 months
w/o EmcBarrel	27.44	2.2×10^{-3}	6.9 months	5.7 years	57 years
w/o FwdSpec	23.67	2.8×10^{-5}	3.6 days	1.2 months	1.0 years
w/o DiscDirc	28.67	1.6×10^{-5}	1.4 days	14.5 days	4.8 months
w/o MvdGem	8.12	1.0×10^{-5}	10.1 days	3.7 months	3.1 years

$J/\psi \to \mu^+\mu^-$

Detector Setup	ϵ_s (%)	ϵ_b	t ($\mathcal{L} = 10^{32}$)	t ($\mathcal{L} = 10^{31}$)	t ($\mathcal{L} = 10^{30}$)
Full	38.83	3.2×10^{-4}	15.1 days	5.0 months	4.2 years
w/o EmcBarrel	36.51	3.7×10^{-4}	19.8 days	6.6 months	5.5 years
w/o FwdSpec	32.15	3.0×10^{-4}	20.7 days	6.9 months	5.7 years
w/o DiscDirc	36.69	2.5×10^{-4}	15.9 days	5.3 months	4.4 years
w/o MvdGem	9.13	4.9×10^{-5}	1.4 months	1.2 years	11.0 years

$\bar{p}p \to X(3872) \to J/\psi\pi^0\pi^0 \to \ell^+\ell^-\pi^0\pi^0$

$$\bar{p}p \to X(3872) \to J/\psi\pi^0\pi^0 \to \ell^+\ell^- 4\gamma$$

$\bar{p}p \to X(3872) \to J/\psi\pi^0\pi^0 \to \ell^+\ell^-4\gamma$

Cross sections

Signal

Assumption:
$\sigma(\bar{p}p \to X(3872) \to J/\psi\pi^0\pi^0) \sim 50$ nbarn
Martin J.Galuska, Master Thesis

Background

Background: $\bar{p}p \to \pi^+\pi^-\pi^0\pi^0$:
$\sigma(4.351 \text{ GeV})=0.050$ mb
CERN-HERA 70-03 (1970)

- Fast Simulation
- $J/\psi \to e^+e^-$; $J/\psi \to \mu^+\mu^-$; $\pi^0 \to \gamma\gamma$
- PID for Electrons: 1 Electron Loose; 1 Electron Tight (as in the Physics Book)
- PID for Muons: 1 Muon Loose; 1 Muon Tight (as in the Physics Book)
- Bremsstrahlung effect for the electrons
- MC Truth Match
- 10.000 events generated
- Decay model: $X(3872) \to J/\psi\pi^0\pi^0$: PHSP
- Decay model: $J/\psi \to \ell^+\ell^-$: VLL
- Decay model: $\pi^0 \to \gamma\gamma$: PHSP

4C fit is performed and best $X(3872)$ candidate in each event is selected by minimal χ^2

Significance

$$Significance(t) = \sqrt{\mathcal{L}t} \times \frac{\sigma_s \epsilon_s f_{BR}}{\sqrt{\sigma_s \epsilon_s f_{BR} + \sigma_b \epsilon_b}}$$

Assumption: σ_s=50 nb [Martin J.Galuska, Master Thesis]
ϵ_s: known from simulation
σ_b=0.050 mb [CERN-HERA 70-03 (1970)]
ϵ_b=known from simulation
$f_{BR} = BR(X(3872) \to J/\psi \pi^0 \pi^0) \times BR(J/\psi \to \ell^+ \ell^-) = 2.97 \times 10^{-3}$
Assumption: $BR(X(3872) \to J/\psi \pi^0 \pi^0) = 0.05$ [Martin J.Galuska, Master Thesis]

$$BR(J/\psi \to e^+ e^-) = \begin{cases} \mathrm{BR}(\mathrm{J}/\psi \to e^+ e^-) = 0.0594 \text{ [PDG]} \\ \mathrm{BR}(\mathrm{J}/\psi \to \mu^+ \mu^-) = 0.0593 \text{ [PDG]} \end{cases}$$

Time needed to achive 5σ significance?

$\bar{p}p \to X(3872) \to J/\psi\pi^0\pi^0 \to \ell^+\ell^-4\gamma$

$J/\psi \to e^+e^-$

Detector Setup	ϵ_s (%)	ϵ_b	t ($\mathcal{L} = 10^{32}$)	t ($\mathcal{L} = 10^{31}$)	t ($\mathcal{L} = 10^{30}$)
Full	38.57	2.0×10^{-4}	9.6 days	3.1 months	2.6 years
w/o EmcBarrel	11.20	8.5×10^{-4}	16.0 months	13.3 years	133 years
w/o FwdSpec	21.91	3.4×10^{-4}	1.6 months	1.4 years	13.9 years
w/o DiscDirc	36.98	2.3×10^{-4}	11.9 days	3.9 months	3.3 years
w/o MvdGem	20.74	3.1×10^{-4}	1.7 months	1.4 years	14.2 years

$J/\psi \to \mu^+\mu^-$

Detector Setup	ϵ_s (%)	ϵ_b	t ($\mathcal{L} = 10^{32}$)	t ($\mathcal{L} = 10^{31}$)	t ($\mathcal{L} = 10^{30}$)
Full	61.20	8.8×10^{-4}	16.0 days	5.6 months	4.6 years
w/o EmcBarrel	17.30	9.0×10^{-4}	7.1 months	5.9 years	59 years
w/o FwdSpec	35.76	8.9×10^{-4}	1.9 months	1.6 years	16.3 years
w/o DiscDirc	58.61	8.0×10^{-4}	16.6 days	5.5 months	4.6 years
w/o MvdGem	30.67	9.5×10^{-4}	2.4 months	2.0 years	19.9 years

Conclusion

- $\chi_{c12} \to J/\psi\gamma$:
  - required integrated luminosity: 5 pb^{-1} [Assumption: cross section 2 nb, s=1000 reconstructed signal events, Efficiency 50%]
  - EMC barrel is essential for photons detection
  - MVD+GEM are important for tracking and vertex reconstruction
  - It seems nor FwdSpec nor DiscDirc are relevant for this channel
- $X(3872) \to J/\psi\pi^+\pi^-$:
  - required integrated luminosity: 22 pb^{-1} [Assumption: cross section 50 nb, s=1000 reconstructed signal events, Efficiency 30%]
  - EMC barrel is relevant for e^+e^- channel
  - MVD+GEM are important for tracking and vertex reconstruction
  - It seems nor FwdSpec nor DiscDirc are relevant for this channel
- $X(3872) \to J/\psi\pi^0\pi^0$:
  - required integrated luminosity: 22 pb^{-1} [Assumption: cross section 50 nb, s=1000 reconstructed signal events, Efficiency 30%]
  - EMC barrel is is essential for photons detection
  - MVD+GEM and FwdSpec are important for tracking and vertex reconstruction
  - It seems that DiscDirc is not relevant for this channel

With $\mathcal{L}/10$ some measurements can still be done (especially for e^+e^- channel), but with $\mathcal{L}/100$ these charmonium processes lose the competitiveness.